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Use of Udaipur rock phosphate with different amendments in improving phosphorus availability and hybrid Napier grass yield in acid soils of Odisha, India

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Abstract
A pot culture study was conducted during February, 2014 to evaluate the effect of Udaipur Rock Phosphate (URP) alone or in combination with amendments like farmyard manure, PSB, lime or SSP on yield, P and Ca uptake by hybrid Napier grass in three different acid soils (Typic Halpludalf) in Odisha, India. The experiment was conducted in a completely randomized design (CRD) with three replications and 18 treatments consists of 3 low pH soils - S_1 (pH-4.15), S_2 (pH-5.03), S_3 (pH-5.82) and six rock phosphate treatments - T_1-Control, T_2-200%P through URP, T_3-50%P through URP+50%P through SSP,T_4- 100% P through URP +FYM @ 5tha^{-1}, T_5-100%P through URP +PSB @ 10 kg ha^{-1} and T_6-100% P through URP + lime @ 0.2 LR (Lime Requirement).The URP contains 7.8% total P, 25.6% Ca,0.26%Mg and 0.24% K indicating a moderate reactive material. The first cut was made after 60 days after planting and subsequently seven cuts were made at an interval of 45 days. The results showed that the available P in URP treatments increased over the initial value, attained its peak at 2nd cutting, there after declined but remained above the initial value upto 8th cutting. Application of URP @ 200 % P recorded higher biomass yield and RAE by hybrid Napier grass in lower pH soils (S_1 and S_2) whereas, URP+SSP recorded maximum yield in S_3. Phosphorus, Ca and S uptake by hybrid Napier grass were highest in URP+SSP followed by URP and URP + lime. There were significant correlations between soil available P and total P uptake (R^2 = 0.946**), P uptake and biomass yield (R^2 =0.963**) and available P and biomass yield (R^2 = 0.969**). Significant correlationship between Ca uptake and biomass yield (R^2 = 0.964**) and S uptake and biomass yield (R^2 = 0.941**) were also observed. The rate of dissolution of phosphate rock as indicated by soil pH, available P and Ca was maximum in low pH soil and safely recommended for crop production as against costly water soluble P fertilizer.

Keywords: hybrid napier grass, Udaipur rock phosphate, SSP, acid soils, lime, PSB, farmyard manure

Introduction

Acid soils in India occupies about 90 million ha (Mha) out of which 49 Mha have pH less than 5.5. The supply of soil phosphorus has been a major limiting factor in crop production due to high P fixation. When a water soluble phosphate fertilizer is added to soil, a series of chemical reaction may take place. The dissolved P reacts with dissolved Ca (In high pH soils) or dissolved Fe and Al (In low pH soils) becomes more stable, forming precipitation with Fe, Al, Ca that are less available to plants (Barrow, 1983) [6]. In acid soils much of P is adsorbed by reacting with Fe, Al and clay minerals or Al that is associated with organic matter (Huges and Gilkes, 1994) [24]. All these reactions can resulted in decreasing P availability over time. (Hedley and McLaughlin, 2005, Syers *et al*., 2008) [22, 42]. The direct use of phosphate rocks may be an economically viable alternative source of P-fertilizers in tropics. The developing countries like India can save huge amount of foreign exchange if phosphate rock (PR) can be used alone or with P-fertilizer in acid soils.

The PR deposits in India including all grades and types is of 260 million tonnes out of which 15.27 million tonnes of high grade. The low grade PR is unacceptable to P-fertilizer industry due to its low P_2O_5 and high $CaCO_3$ content and could be a cheaper P source for small and marginal farmers in acid soil regions. The efficiency of phosphate rock depends on its solubility which is influenced by chemical and mineralogical characteristics of rocks, soil properties, crops and climatic conditions (White, 1988b) [48]. The dissolution of phosphate rocks depends on the H+ ion supply power of soils (Wheeler and Edmeades, 1984) [47] activities of Ca^{2+} and $H_2PO_4^-$ ions in soil solution (Kirk and Nye, 1986b). Mishra and Pattanaik (1997), Pattanaik (1988), Dash *et al*., (1988) [27, 30, 12, 12] evaluated the efficiency of several Indian phosphate rocks with North Carolina, Gafsa, Florida, Morocco and found all the Indian phosphate rocks showed lower efficiency as compared to North Carolina with respect to yield and P availability.

Liming of acid soils is a common practice to raise soil pH and decrease Al toxicity for optimal crop growth. However, the higher pH and increased exchangeable Ca resulting from liming are detrimental to PR dissolution (Hammond *et al*., 1986b, Mishra and Pattanaik, 1997) [19, 30]. Hence, lime rates should be carefully chosen to alleviate the Al toxicity problem and, at the same time, to avoid adverse effects on PR dissolution in acid soils (Chien and Friesen 1992) [11]. Application of phosphate solubilising biofertilizer (PSB) enhances dissolution of PR through production of organic acid and chelating substances (Sanyal and Saha, 1988, Adhya *et al*., 2015) [37, 1]. Organic manures supplies plant nutrients such as P through decomposition and the organic acids produced in this process chelate P-fixing elements in the rhizosphere or decomposition system. Several studies showed that application of SSP and PR mixture in 1:1 ratio increased the dry matter yield and P, Ca and Mg uptake by maize, groundnut, and linseed in acid soils (Mitra and Mishra, 1991, Das *et. al*., 1990, Dwivedi and Dwivedi, 1990) [31, 13, 15].

Although sizeable informations are available on rate of PR dissolution either alone or in combination with different amendments, still informations are lacking in published data dealing with direct use of Udaipur rock phosphate in acid soil region of Odisha, India.

In view of the above said knowledge gaps, a pot culture study was carried out to evaluate the use of Udaipur rock phosphate with different amendments in improving phosphorus availability and biomass yield of hybrid napier grass in three different acidic laterite soils.

Materials and Methods

Three acidic laterite soil samples in bulk from plough layers (0-15cm) were collected from farmer's field having maize-groundnut cropping system from Dhenkanal block of Dhenkanal district, Odisha. The collected soil samples were air dried, processed and used for pot culture experiment and laboratory analysis. Particle size was determined by Bouyoucos hydrometer method (Bouyoucos, 1962) [9], pH by glass electrode with Calomel as standard (Jackson, 1973) [25]. Organic carbon was determined by wet digestion method of Walkley and Black (1934) [46]. The cation exchange capacity was determined by Schollenberger and Simon (1945) [38]. Exchangeable Ca and Mg was determined by EDTA (Versenate) titration method (Gupta, 2007), exchangeable acidity and Al by the procedure outlined by McLean (1965).Available N in soils was determined by modified alkaline permanganate method (Subbiah and Asija, 1956) [40], available P by Bray's 1 method (Bray and Kurtz, 1945) [10] and available K by ammonium acetate method (Hanway and Heidel, 1952) [21]. The lime requirement value was determined by Woodruff Buffer method (Woodruff, 1948) [49].

Nitrogen content in soil samples and organic manure was determined by Kjeldhal digestion method as described in AOAC (1995) [5]. The plant samples was pre-digested in diacid mixture (HNO_3:$HClO_4$ - 3:2 ratio) for estimation of P, K, Ca, and S. The P and S were estimated by spectrophotometer, K by flame photometer and Ca by EDTA titration method (Jackson, 1973) [25].

A pot culture experiment was carried out during February, 2014 in the green house of Department of Soil Science and Agricultural Chemistry, Orissa University of Agriculture and Technology, Bhubaneswar, Odisha. The experiment was conducted in a completely randomized design (CRD) with two replications and 18 treatments consists of 3 types of soils - S_1 (pH-4.15), S_2 (pH-5.03), S_3 (pH-5.82) and each soil was superimposed with six rock phosphate (PR) treatments- T_1-Control, T_2-200%P through RP, T_3-50%P through RP+50%P through SSP,T_4- 100%P through RP +FYM @5tha^{-1}, T_5-100%P through RP +PSB @ 10 kg ha^{-1} and T_6-100% P through RP + lime @ 0.2 LR (Lime Requirement).

The polyethylene lined earthen pots were rinsed in 0.1N HCl followed by deionised water. Seven kg of soil was transferred into each pot. Each pot received a common dose of N @40 kg ha^{-1} through urea and K_2O@40 kg ha^{-1} through mutate of potash. Phosphate @40kgP_2O_5 ha^{-1} was applied through Udaipur rock Phosphate or SSP as per the treatments. Well decomposed FYM was added @ 5tha^{-1} in T_4. In T_6, pure $CaCO_3$ was added @ 0.2LR. The LR for different soil was: S_1-5.8qha^{-1}, S_2-4.8qha^{-1}, and S_3-3.3qha^{-1}. On soil weight basis, the fertilizers, FYM and PSB were calculated, mixed thoroughly with 7kg of soil before planting. One slip of Bajra napier hybrid grass (*Pennisetum glaucum*) × (*Pennisetum purpureum*) was planted in each pot, watering with deionised water and plant protection measures were taken as and when necessary. The first cut was made after 60 days after planting and subsequently seven cuts were made at an interval of 45 days. Soil samples were collected from each treatments during cutting. After each cut, each pot received N@ 40kg ha^{-1} through urea solution. After recording the dry mass yield of grass at each cut, the samples were washed with acidified solution, rinsed with deionised water, dried at 65 degree centigrade in a hot air oven, grinded and kept for analysis. The dry powdered grass samples were digested with diacid mixture on a hot plate and filtered through what man No.42 filter paper for estimation of P, Ca and S. The soil samples were air dried sieved through 8 mesh sieve and analysed for pH, available P and exchangeable Ca. Simple co-relation was carried out to establish the relationships between nutrients and soil properties.

Results

Characteristics of soil, rock phosphate and farmyard manure used in study

The Alfisols used in this study were very acidic having pH: S_1-4.15, S_2-5.03 and S_3-5.82. The soil texture varied from sandy loam to sandy clay loam. The soils had low to medium in organic carbon content, available P but low in available N and cation exchange capacity. Available K was medium to high (Table 1).

The URP used had 7.8% total P, 25.6% Ca, 0.26% Mg and 0.24% K, indicating a moderate reactivity of the material (Table 2).

The farmyard manure sample had 1.2% N, 0.006% P and 0.045% Ca indicating a higher sink for P and Ca during dissolution of rock phosphate (Table 3).

Table 1: Physical and chemical properties of the soil

Soil type	Sand (%)	Silt (%)	Clay (%)	Textural class	pH	Exch. Acidity c mol (P^+)/kg	Exch. Al c mol (P^+)/kg	Exch. Ca c mol (P^+)/kg	Exch. Mg c mol (P^+)/kg	CEC c mol (P^+)/kg	OC (%)	Av. N (kgha^{-1})	Av. P (kgha^{-1})	Av. K (kgha^{-1})	LR ($CaCO_3$ qha^{-1})
S_1	81.4	7.0	11.6	Sandy loam	4.15	0.86	0.55	1.32	0.32	3.2	0.47	137.5	8.9	200.5	58.0
S_2	74.6	7.8	17.6	Sandy loam	5.03	0.40	0.22	1.37	0.40	3.8	0.45	125.0	12.2	162.1	48.0
S_3	75.8	4.1	20.1	Sandy clay loam	5.82	0.36	0	1.50	0.48	4.5	0.58	158.5	15.7	323.6	33.0

Table 2: Chemical composition of Udaipur rock phosphate (URP) used in this study

Parameter	Magnitude (%)
P	7.8
S	1.2
Ca	25.6
Mg	0.26
K	0.24

Table 3: Chemical composition of farmyard manure used in this study

Parameter	Magnitude (%)
N	1.2
O.C.	0.75
P	0.006
K	0.25
Ca	0.045

Soil available phosphorus at different stages of cutting

The available phosphorus content in control generally decreased with progress of growth of hybrid Napier grass. The magnitude of depletion was highest (5.51 kg ha^{-1}) in S_3 (pH-5.82) followed by 3.83 kg ha^{-1} in S_2 (pH-5.03) and 2.71 kg ha^{-1} in S_1 (pH-4.15) might be due to P uptake by grass in absence of any external P source (Table 4 and Fig.1). The available P content in other treatments increased over the initial value, attained its peak at 2nd cutting, there after declined but remained above the initial value at the end of 8th cutting. This indicates that P released through dissolution of URP alone or combined with SSP, FYM or PSB could meet crop requirement during growing period. Combined application of URP+SSP (T_3) recorded highest available P since, water soluble SSP meet the crop requirement Pat initial stage and dissolution of URP build up the P status and also meet crop requirement in long run. Sole application of URP at higher dose (200%P) was better than URP+FYM or URP+PSB or URP+lime treatment but can be compared with URP+SSP treatment in long run. Higher available P in T_2 (200% P through URP) treatment resulted in higher dissolution of URP in soils with pH varying from 4.15 to 5.82. Inclusion of lime with URP increased the soil pH that lower down dissolution rate of URP although calcium in lime decreases Al toxicity and helps better crop growth and biomass production. Inclusion of FYM with URP was better than URP+ PSB treatment since, FYM increases available P in soil through chelation and decomposition.

Several authors cited that the availability of P in soil indicates the rate of dissolution of PRs. Mishra and Pattanaik (1997) [30] found that the release of P in acid soil from North Carolina PR was about 71 % of P in rock followed by 48 % in Jordan PR and 10-46 % in Indian phosphate rocks.

Table 4: Change in soil available phosphorus (kg ha^{-1}) at different cuttings

Soils	Treatments	Available P (kg ha^{-1})									
		1st	2nd	3rd	4th	5th	6th	7th	8th	Mean	P build up (kg ha^{-1})
S_1 (pH=4.15) (Initial Av. P=8.92 kg ha^{-1})	S_1T_1=control P	8.49	7.92	7.47	7.14	7.08	6.86	6.57	6.21	7.22	-2.7
	S_1T_2=200%P(URP)	12.11	21.54	20.24	21.93	23.49	22.21	20.89	19.97	20.30	11.0
	S_1T_3=50%P(URP)+50%P(SSP)	13.74	25.79	22.63	20.81	23.87	22.65	20.18	17.81	20.94	8.9
	S_1T_4=100%P(URP)+OM	11.53	19.68	17.33	16.27	17.48	17.92	15.39	14.66	16.28	5.7
	S_1T_5=100%P(URP)+Biof	11.26	19.23	16.98	16.03	17.34	17.24	14.56	13.72	15.80	4.8
	S_1T_6=100%P(URP)+Lime	13.85	24.87	23.79	19.86	21.84	19.59	16.05	15.75	19.45	6.83
S_2(pH=5.03) (Initial Av. P=12.17 kg ha^{-1})	S_2T_1=control P	11.71	10.76	10.23	9.53	9.21	8.77	8.61	8.34	9.65	-3.8
	S_2T_2=200%P(URP)	15.85	27.72	25.91	28.82	32.29	30.29	27.77	26.69	26.92	14.5
	S_2T_3=50%P(URP)+50%P(SSP)	17.94	32.89	29.04	27.55	30.69	29.13	25.3	24.48	27.13	12.3
	S_2T_4=100%P(URP)+OM	14.63	25.37	22.28	21.5	23.59	23.7	20.36	19.76	21.40	7.6
	S_2T_5=100%P(URP)+Biof	14.28	24.94	20.51	21.49	25.43	25.07	20.37	18.55	21.33	6.4
	S_2T_6=100%P(URP)+Lime	18.1	33.71	32.14	26.11	30.01	27.9	21.33	21.16	26.31	9.0
S_3(pH=5.82) (Initial Av. P=15.74 kg ha^{-1})	S_3T_1=control P	14.63	13.42	12.71	12.45	11.89	11.47	10.83	10.23	12.20	-5.5
	S_3T_2=200%P(URP)	19.18	31.37	29.55	31.48	35.12	33.65	30.11	28.54	29.88	12.8
	S_3T_3=50%P(URP)+50%P(SSP)	23.32	40.63	36.16	32.54	33.64	32.26	28.7	27.18	31.80	11.4
	S_3T_4=100%P(URP)+OM	18.94	30.67	28.25	27.52	29.21	28.41	25.13	22.49	26.33	6.8
	S_3T_5=100%P(URP)+Biof	18.43	29.89	28.49	26.51	27.31	26.75	22.85	20.38	25.08	4.6
	S_3T_6=100%P(URP)+Lime	21.67	33.52	31.34	28.79	30.74	30.41	27.36	23.87	28.46	8.1
CD (0.05)	S	0.91	0.87	1.01	0.64	0.93	0.81	0.72	0.52	0.55	-
	T	1.28	1.23	1.43	0.91	1.31	1.15	1.02	0.73	0.78	-
	S x T	NS	2.13	2.49	1.57	2.27	1.99	1.77	1.27	1.36	-
C.V. (%)	-	6.82	4.02	5.13	3.41	4.52	4.12	4.23	3.20	3.02	-

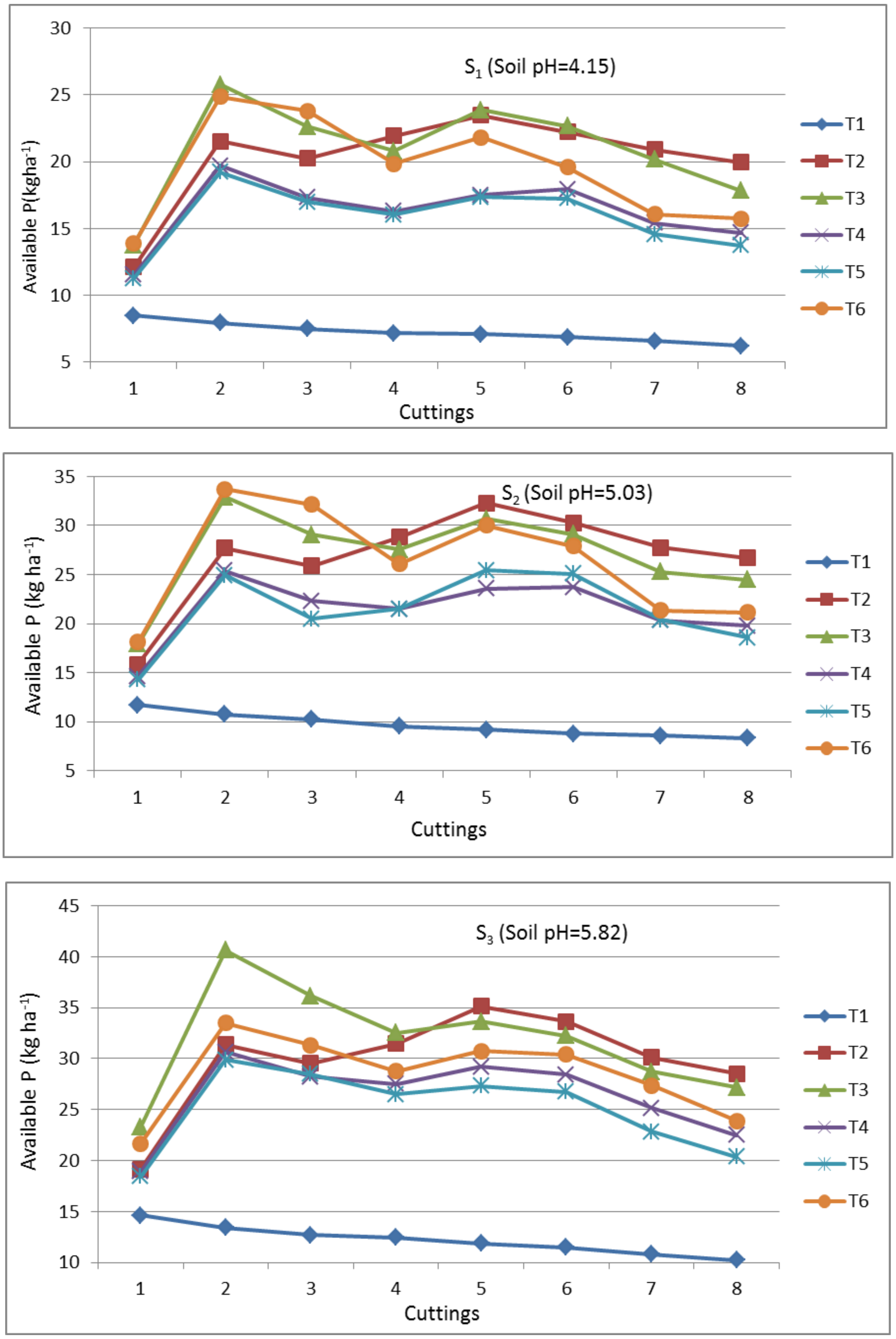


Fig 1: Change in available phosphorus of soil at different cuttings

Biomass yield of hybrid Napier grass at different stages of cutting

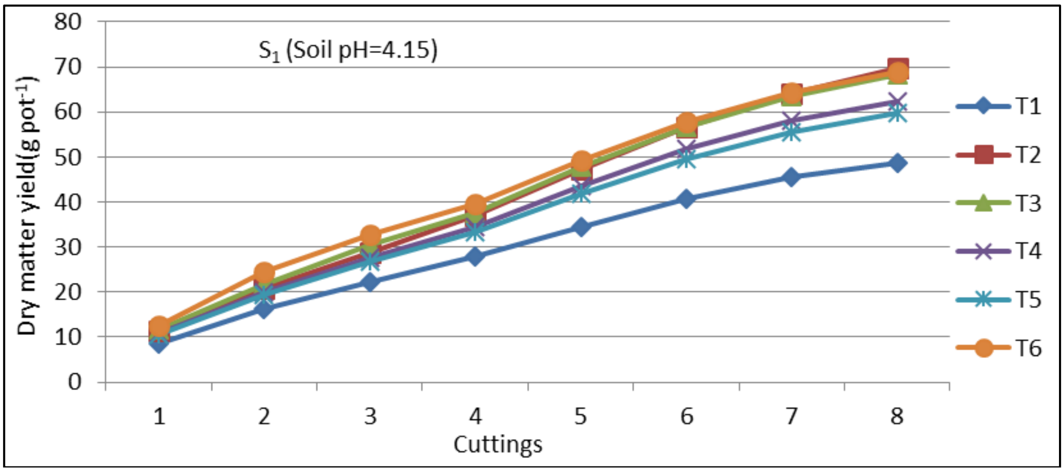
The cumulative biomass yield of hybrid Napier grass increased significantly in URP treatments compared to that in the control. The magnitude of increase in URP treatments varied from 23-44 % in S_1, 20-41 % in S_2, and 27-47 % in S_3 (Table 5 and Fig.2). Sole application of higher dose of URP (200%P-T_2) recorded higher biomass yield than other treatments in S_1 (pH-4.15) and S_2 (pH-5.03) whereas, URP+SSP (T_3) treatment recorded maximum yield in S_3 (pH-5.82) might be due to dissolution of URP got slower with increased soil pH. The effect of URP+SSP or URP+ lime treatment in S_1 and S_2 were at par but, lower than URP alone (T_2). Combined application of URP+FYM or URP+ PSB recorded lower yield as compared to other treatments except control.

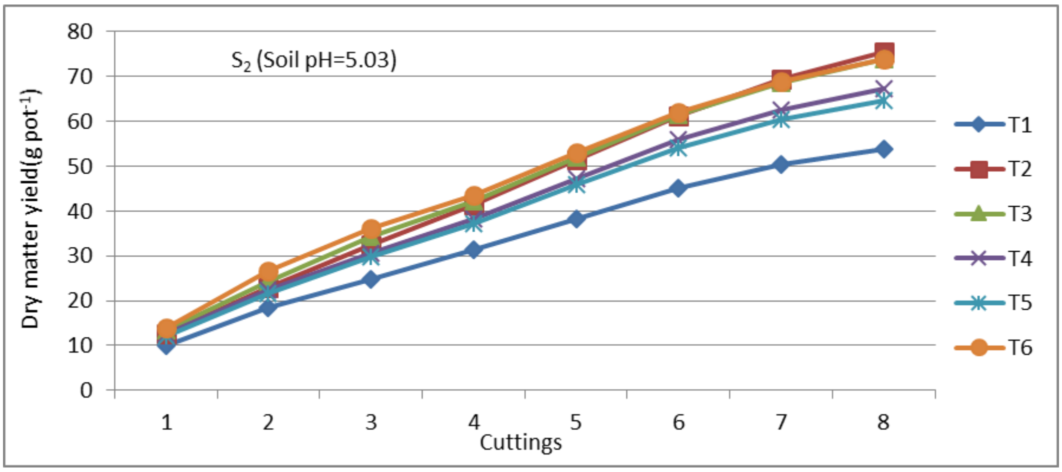
The relative agronomic efficiency (RAE) of treatments was calculated taking URP+SSP (T_3) treatment as standard. The sole application of higher dose of URP (T_2) recorded higher RAE than standard treatments in S_1 (107%) and S_2 (108%), but the efficiency decreased in S_3 (76%) with increasing pH. The efficiency of URP greatly influenced by soil pH. The high RAE values of URP obtained in this study can be attributed to low soil pH which enhanced the solubility of URP (Table 5).

Table 5: Dry matter yield of hybrid napier grass (g pot^{-1}) at different cuttings

Soils	Treatments	Dry matter yield(g pot^{-1})										
		1st	2nd	3rd	4th	5th	6th	7th	8th	Total	% increase in yield over control	RAE (%)
Soil S_1 (pH=4.15)	S1T1=control P	8.44	7.77	5.93	5.78	6.53	6.10	4.83	3.18	48.54^{a}	-	-
	S1T2=200%P(RP)	11.27	9.49	8.12	8.09	10.40	9.31	7.47	5.67	69.80^{fgh}	43.7	107
	S1T3=50%P(RP)+50%P (SSP)	11.55	10.05	8.85	7.27	10.01	9.03	6.64	4.97	68.35^{fg}	40.7	100
	S1T4=100%P(RP)+OM	10.93	9.04	7.61	6.92	9.17	8.21	6.11	4.42	62.38^{cde}	28.4	70
	S1T5=100%P(RP)+Biof	10.63	8.63	7.46	6.56	8.61	7.80	5.82	4.33	59.82^{cd}	23.2	57
	S1T6=100%P(RP)+Lime	12.55	11.95	8.15	6.84	9.87	8.57	6.34	4.66	68.89^{fgh}	41.8	103
Soil S_2 (pH=5.03)	S2T1=control P	9.94	8.61	6.35	6.52	6.76	6.94	5.27	3.37	53.73^{b}	-	-
	S2T2=200%P(RP)	12.61	10.35	9.45	8.94	10.11	9.70	8.17	6.30	75.61^{ij}	40.7	108
	S2T3=50%P(RP)+50%P (SSP)	13.41	10.80	10.21	7.89	9.62	9.54	7.27	5.31	74.02^{hij}	37.7	100
	S2T4=100%P(RP)+OM	12.56	9.76	8.35	7.54	9.13	8.69	6.46	4.74	67.21^{ef}	25.1	60
	S2T5=100%P(RP)+Biof	12.20	9.44	8.23	7.34	8.72	8.23	6.20	4.37	64.71^{def}	20.4	54
	S2T6=100%P(RP)+Lime	13.89	12.70	9.61	7.47	9.45	9.01	6.71	4.95	73.77^{ghij}	37.3	99
Soil S_3 (pH=5.82)	S3T1=control P	10.22	9.14	8.08	6.61	7.27	7.09	5.80	3.48	57.68^{bc}	-	-
	S3T2=200%P(RP)	12.78	10.85	11.24	8.88	9.49	9.80	8.57	6.65	78.24^{ij}	35.7	76
	S3T3=50%P(RP)+50%P (SSP)	14.58	13.39	12.95	8.13	10.17	10.32	9.04	6.08	84.64^{k}	46.7	100
	S3T4=100%P(RP)+OM	13.22	11.35	11.70	7.70	9.08	9.01	8.21	5.11	75.36^{ij}	30.6	66
	S3T5=100%P(RP)+Biof	12.86	11.11	12.20	7.24	8.83	8.50	8.09	4.51	73.33^{ghi}	27.1	58
	S3T6=100%P(RP)+Lime	14.16	13.07	11.85	7.52	9.14	9.17	8.44	5.81	79.14^{j}	37.2	80
CD(0.05)	S	0.58	0.64	0.55	0.51	NS	0.53	0.59	0.36	2.04	-	-
	T	0.27	0.90	0.78	0.73	1.09	0.76	0.83	0.51	2.89	-	-
	SXT	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	-
C. V.(%)		5.54	7.08	6.99	8.05	9.97	7.19	9.74	8.57	3.47	-	-

Total yield followed by same letters in a column are not different at 0.05 probability level





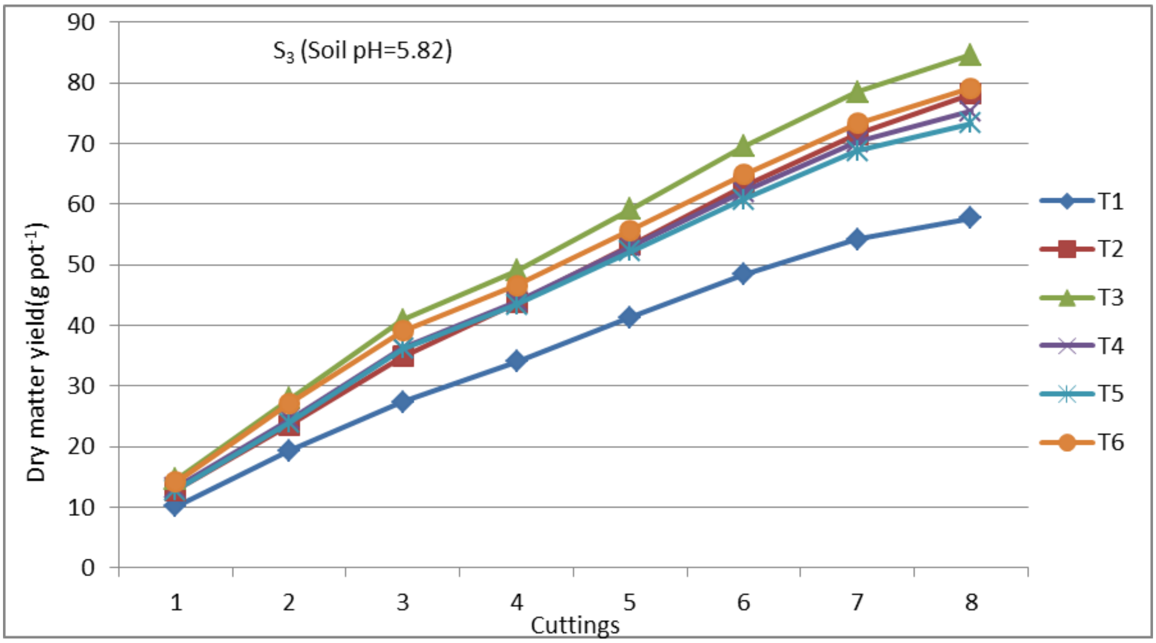


Fig 2: Effect of treatments on cumulative biomass yield of hybrid Napier grass (g pot^{-1})

Phosphorus, calcium and sulphur content and their uptake by hybrid Napier grass

Phosphorus, calcium and sulphur content of hybrid Napier grass in treatments were significantly higher than control at all stages of cuttings. Although URP+SSP treatment recorded maximum P, Ca and S content followed by URP (T_2) and URP+lime (T_6), but there was no significant differences with the treatments (Table 6 and Fig.3).

Phosphorus, calcium and sulphur uptake by hybrid Napier grass in treatments were significantly higher than control, highest being in URP+SSP followed by URP alone and URP+lime. The trend of total P uptake over 8 cuttings was in order of URP+SSP > URP > URP+lime. Considering the initial soil pH, P uptake in URP+SSP treatment was maximum among all treatments might be due to decrease in P fixation with increasing in soil pH (Table 7 and Fig.4).

Calcium uptake by grass increases with increasing initial soil pH. Irrespective of the treatments it was highest in S_3 followed by S_2 and S_1. The treatment receiving URP+SSP recorded maximum Ca uptake followed by URP+lime and URP alone might be due to an additional amount of calcium was added through water soluble SSP. Combined application of URP with FYM or PSB did not effect much although the Ca uptake was higher than control (Table 7 and Fig.5).

Sulphur uptake by the grass in treatments was significantly higher than the control. Irrespective of the treatments, higher uptake was recorded in S_3 followed by S_2 and S_1.Application of URP+SSP resulted in significantly higher S uptake in all soils over URP and URP+lime treatment which were at par. Addition of S through water soluble SSP resulted in higher S uptake as compared to other treatments since additional amount of S was added through SSP. Sinde *et al*. (1978), Das *et al*. (1982) [39, 14] reported similar results.The yield of rice and P uptake in North Carolina PR were higher than water soluble SSP. The efficiency of several Indian PRs such as Udaipur, Massoorie, Jamarkota, Purulia was lower than North Carolina since these rocks contained much lower amount of citrate soluble P as compared to North Carolina PR (Table 7 and Fig.6).

Table 6: Effects of treatments on mean P, Ca and S content (%) of hybrid Napier grass.

Soils	Treatments	P (%)	Ca (%)	S (%)
Soil S_1 (pH=4.15)	S1T1=control P	0.23	0.45	0.08
	S1T2=200%P(RP)	0.29	0.61	0.11
	S1T3=50%P(RP)+50%P(SSP)	0.30	0.64	0.11
	S1T4=100%P(RP)+OM	0.27	0.55	0.10
	S1T5=100%P(RP)+Biof	0.27	0.54	0.10
	S1T6=100%P(RP)+Lime	0.29	0.60	0.11
Soil S_2 (pH=5.03)	S2T1=control P	0.24	0.46	0.09
	S2T2=200%P(RP)	0.29	0.59	0.11
	S2T3=50%P(RP)+50%P(SSP)	0.31	0.62	0.12
	S2T4=100%P(RP)+OM	0.28	0.57	0.10
	S2T5=100%P(RP)+Biof	0.27	0.56	0.10
	S2T6=100%P(RP)+Lime	0.30	0.60	0.11
Soil S_3 (pH=5.82)	S3T1=control P	0.23	0.48	0.09
	S3T2=200%P(RP)	0.29	0.60	0.11
	S3T3=50%P(RP)+50%P(SSP)	0.30	0.62	0.11
	S3T4=100%P(RP)+OM	0.28	0.57	0.10
	S3T5=100%P(RP)+Biof	0.27	0.56	0.10
	S3T6=100%P(RP)+Lime	0.29	0.60	0.11
CD (0.05)	S	0.01	0.01	0.005
	T	0.01	0.02	0.01

	SXT	NS	NS	NS
CV (%)	-	2.81	2.31	5.50

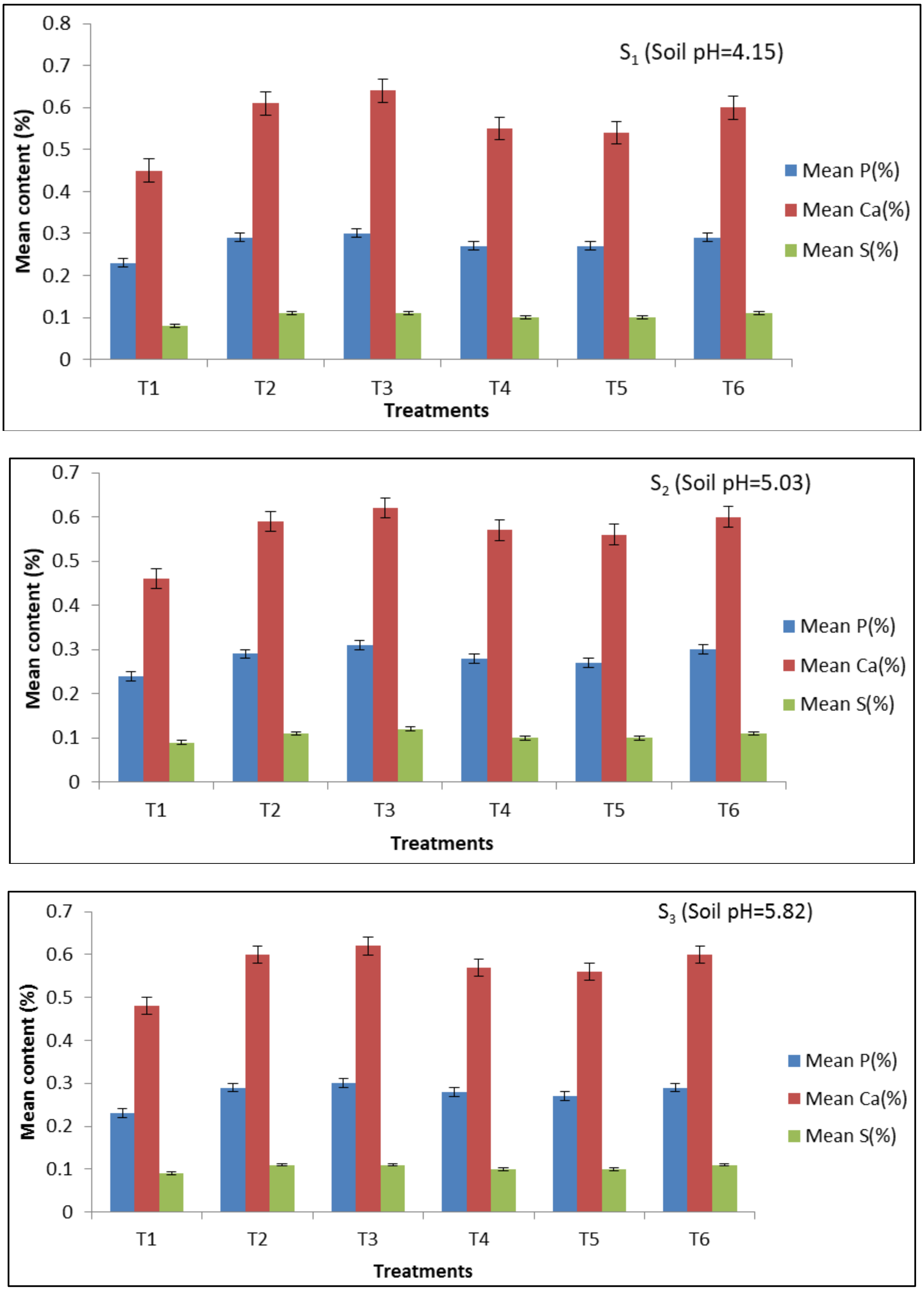


Fig 3: Effect of treatments on mean P, Ca and S content (%) of hybrid napier grass Vertical bars indicate ± SEm

Table 7: Effects of treatments on total P, Ca and S uptake (g pot^{-1}) by hybrid napier grass

Soil	Treatments	Total P uptake	% total P uptake Increase over control	Total Ca uptake	% of total Ca uptake increase over control	Total S uptake	% of total S uptake increase over control
Soil S_1 (pH=4.15)	S1T1=control P	10.84^{a}	-	22.33^{a}	-	3.96^{a}	
	S1T2=200%P(RP)	20.11^{g}	85.5	41.92^{gh}	78.9	7.38^{fg}	86.4
	S1T3=50%P(RP)+50%P(SSP)	20.43^{gh}	88.5	43.58^{hij}	90.4	8.02^{ghij}	102.5
	S1T4=100%P(RP)+OM	16.79^{d}	54.9	34.63^{de}	55.1	6.18^{de}	56.1
	S1T5=100%P(RP)+Biof	15.75^{c}	45.3	32.77^{d}	46.8	5.81^{cd}	46.7

	S1T6=100%P(RP)+Lime	19.50^{fg}	79.9	40.98^{g}	83.5	7.58^{fgh}	91.4
Soil S_2 (pH=5.03)	S2T1=control P	12.79^{b}	-	25.30^{b}	-	4.95^{b}	-
	S2T2=200%P(RP)	22.02^{i}	72.2	44.54^{ijk}	76.0	8.12^{hij}	64.0
	S2T3=50%P(RP)+50%P(SSP)	22.57^{i}	76.5	45.59^{jkl}	80.2	8.70^{j}	75.8
	S2T4=100%P(RP)+OM	18.51^{ef}	44.7	38.30^{f}	51.4	7.22^{f}	45.9
	S2T5=100%P(RP)+Biof	17.68^{de}	38.2	36.35^{ef}	43.7	6.55^{e}	32.3
	S2T6=100%P(RP)+Lime	21.60^{hi}	68.9	44.04^{hij}	74.1	8.30^{ij}	67.7
Soil S_3 (pH=5.82)	S3T1=control P	13.33^{b}	-	28.35^{c}	-	5.31^{bc}	-
	S3T2=200%P(RP)	22.37^{i}	67.8	46.36^{kl}	63.5	8.30^{ij}	56.3
	S3T3=50%P(RP)+50%P(SSP)	25.47^{j}	91.1	51.35^{m}	81.1	9.69^{k}	82.5
	S3T4=100%P(RP)+OM	20.72^{gh}	55.4	42.45^{ghi}	49.0	7.79^{fghi}	46.7
	S3T5=100%P(RP)+Biof	19.84^{g}	48.8	41.25^{g}	45.5	7.38^{fg}	39.0
	S3T6=100%P(RP)+Lime	22.84^{i}	71.3	47.33^{l}	66.9	8.66^{j}	63.1
CD (0.05)	S	0.46	-	0.85		0.26	-
	T	0.65	-	1.20	-	0.37	-
	SXT	NS	-	NS		NS	-
CV (%)	-	2.82	-	2.52	-	4.21	-

Total nutrient (P, Ca or S) uptake followed by same superscript for each factor in a column are not different ($p \leq 0.05$)

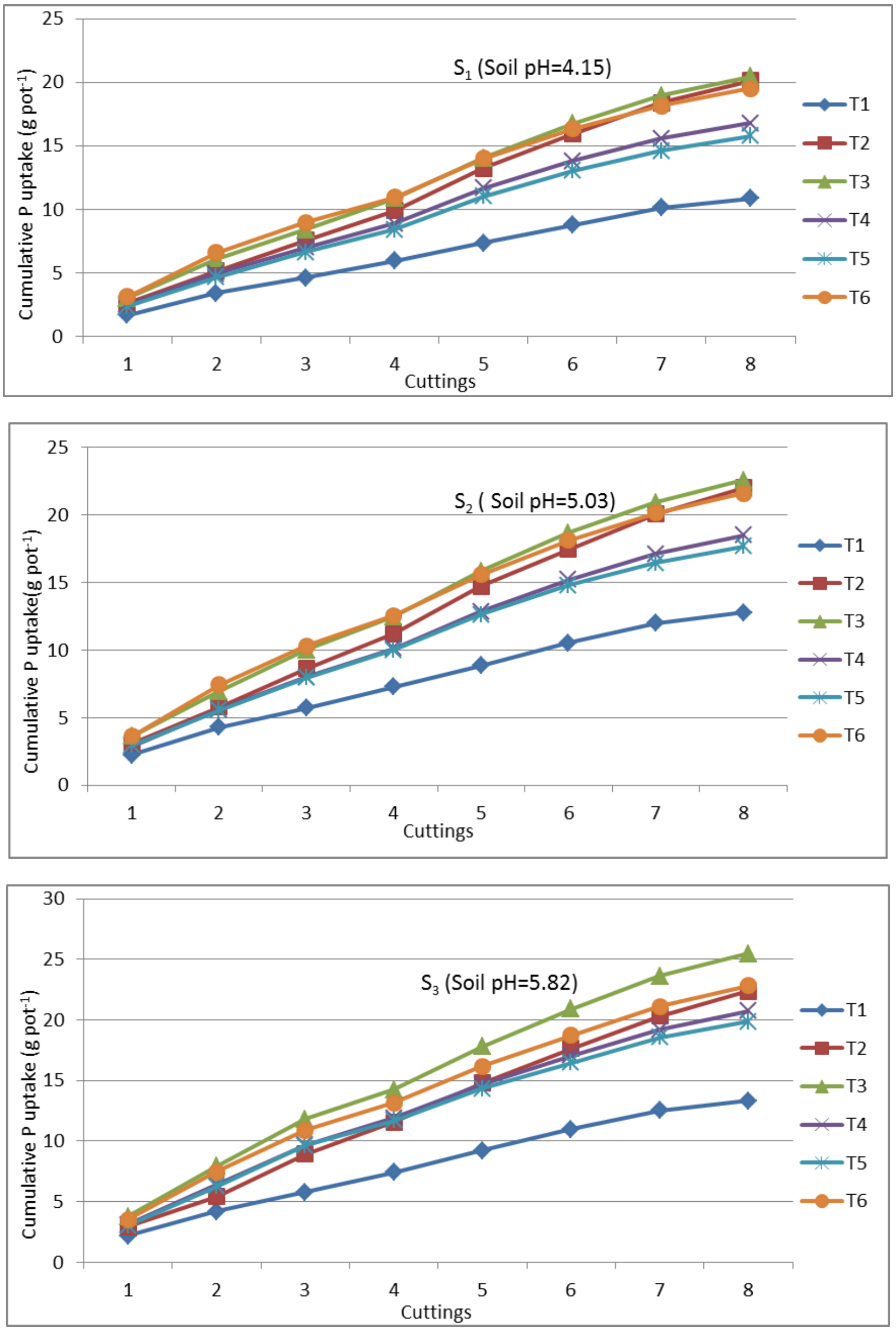


Fig 4: Cumulative phosphorus uptake (g pot^{-1}) at different cuttings

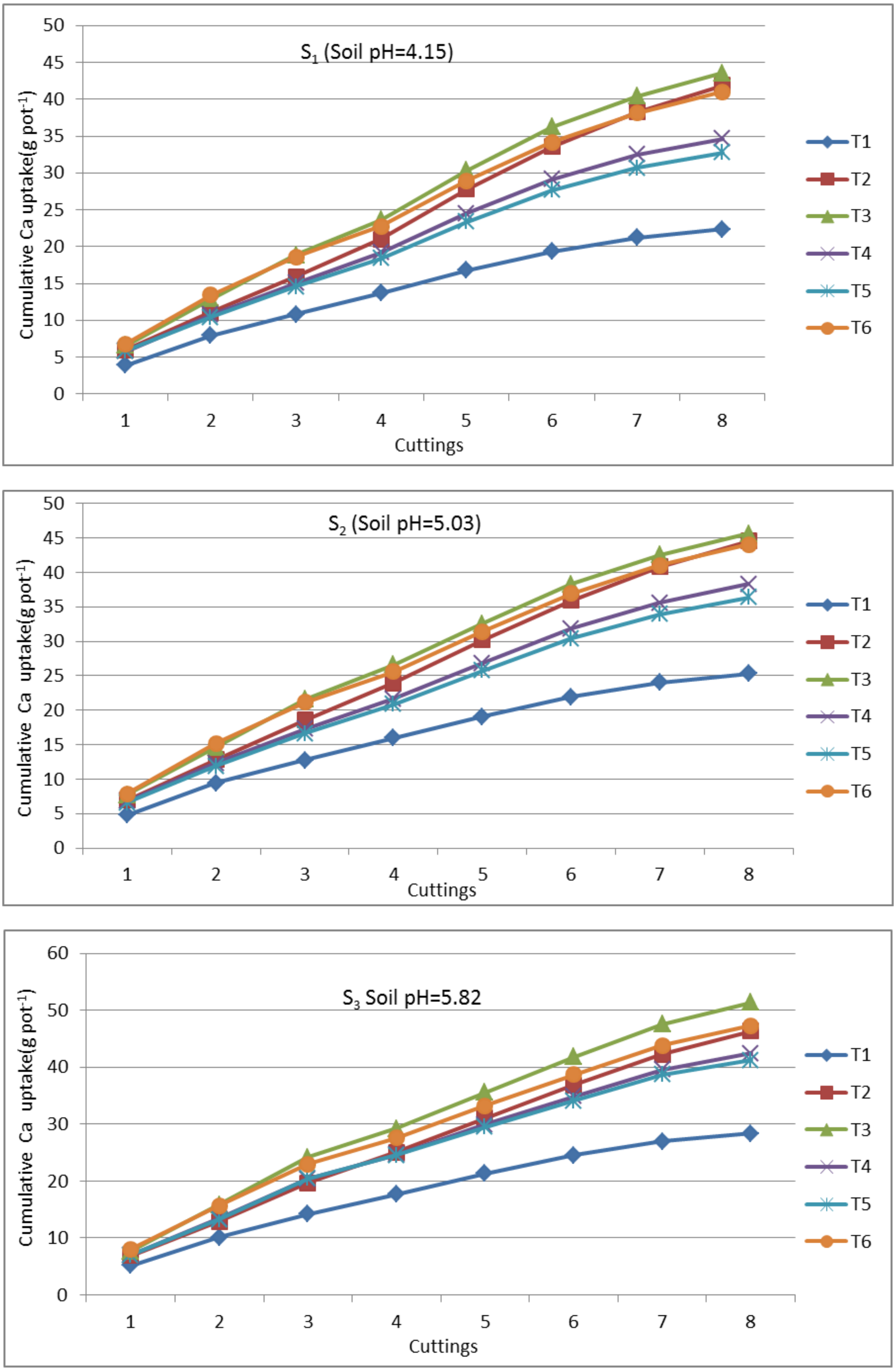


Fig 5: Cumulative calcium uptake (g pot^{-1}) at different cuttings

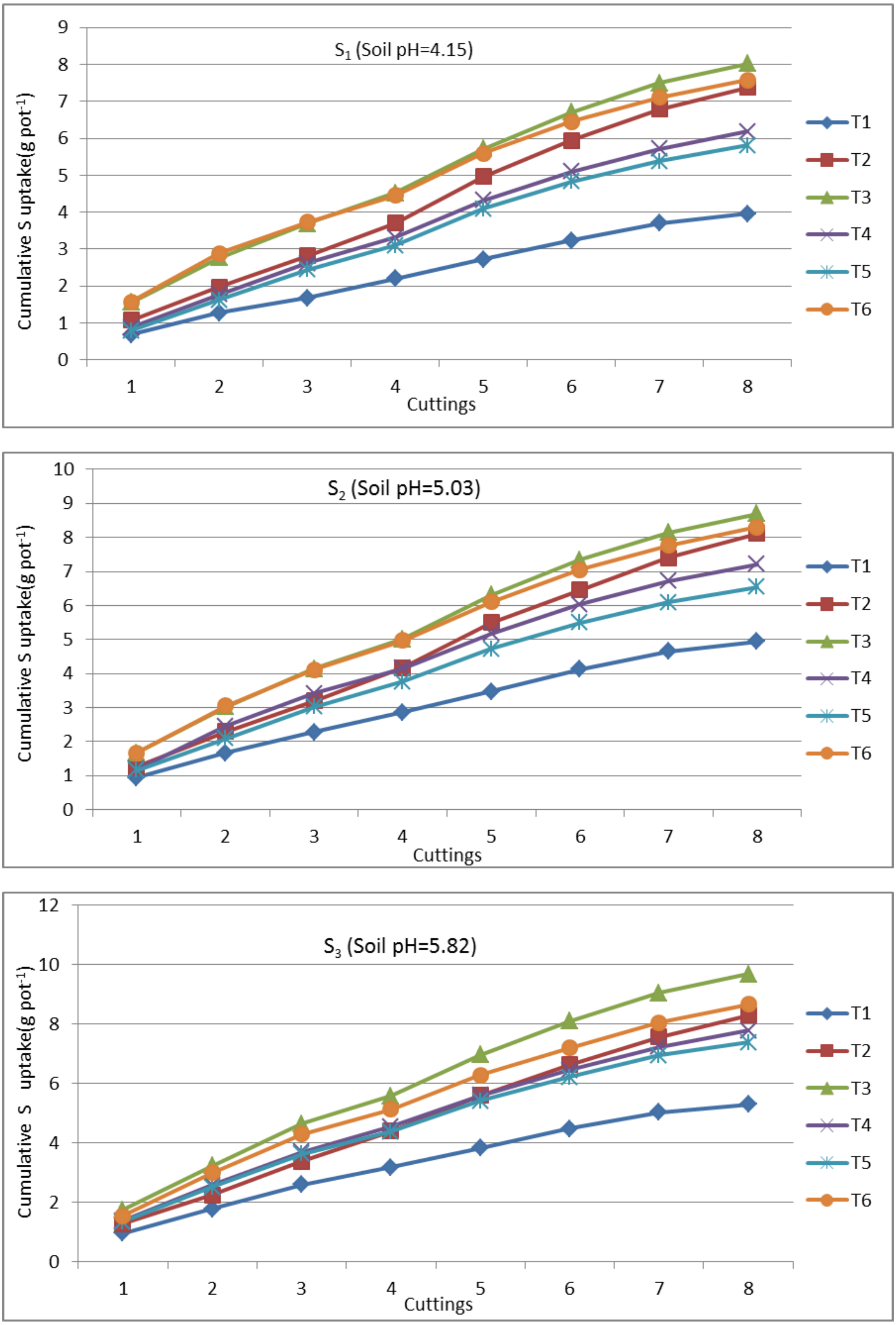


Fig 6: Cumulative sulphur uptake (g pot^{-1}) at different cuttings

Correlation between soil available P, hybrid napier grass yield and P, Ca and S uptake

There were significant correlations between; soil available P and total biomass yield (R^2=0.969**), P uptake and grass yield (R^2=0.963**), and available P and total P uptake (R^2=0.946**) (Fig.7, 8 and 9). The significant correlations for the various parameters measured indicated that the amounts of soil available P derived during dissolution of rock phosphate, influenced P uptake and could explain the yield variations. Phosphorus supplied to grass by amendments is consequently an important condition to achieve higher biomass yield in acid soils. There were significant correlations between total calcium uptake and biomass yield (R^2=0.964**) and total S uptake and biomass yield (R^2=0.941**) of napier grass.The significant correlations for various parameters measured indicated that the exchangeable calcium in soil and their uptake by grass were achieved with higher dissolution rate of URP in acid soils. Sulphur uptake by grass was influenced by the addition of amendments viz. FYM, SSP to the hybrid napier grass.

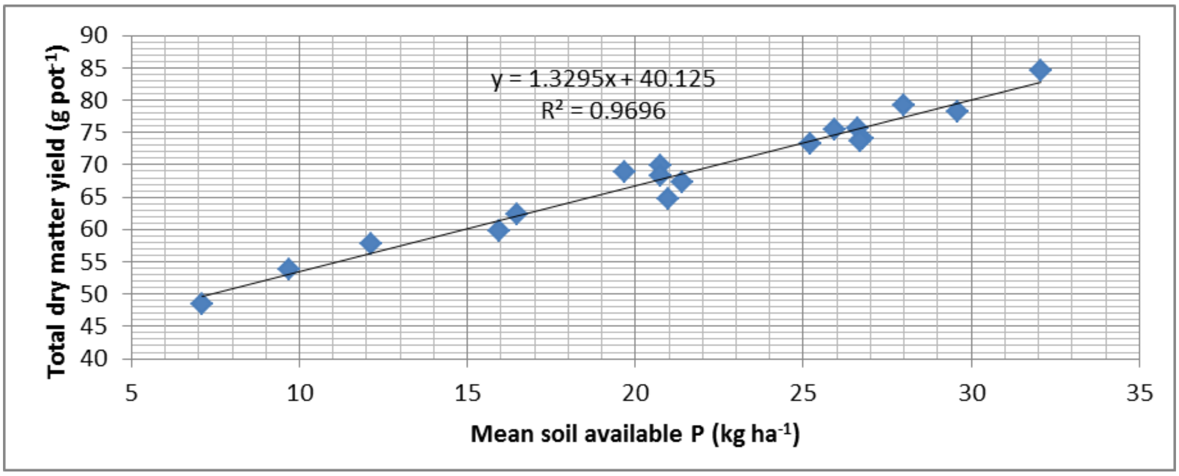


Fig 7: Relationship between mean soil available P and total dry matter yield of hybrid napier grass

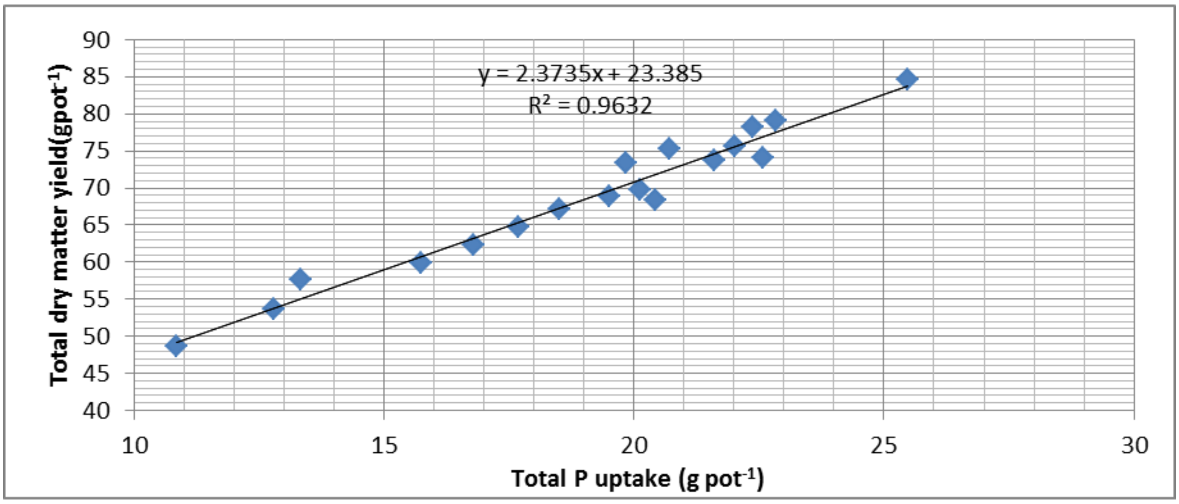


Fig 8: Relationship between total P uptake and total dry matter yield of hybrid napier grass

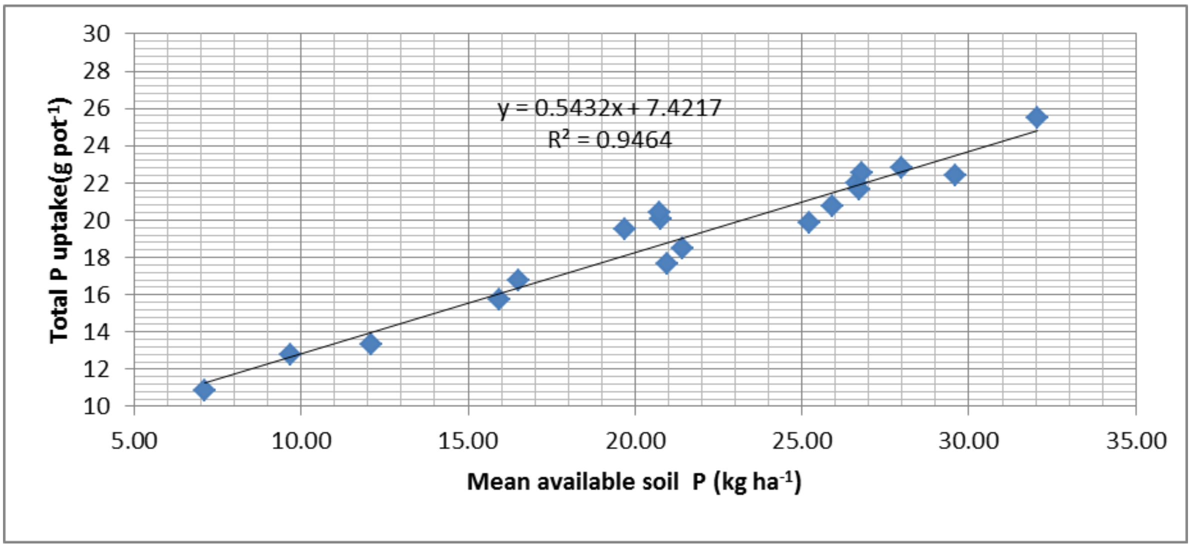


Fig 9: Relationship between mean available soil P and total P uptake of hybrid napier grass

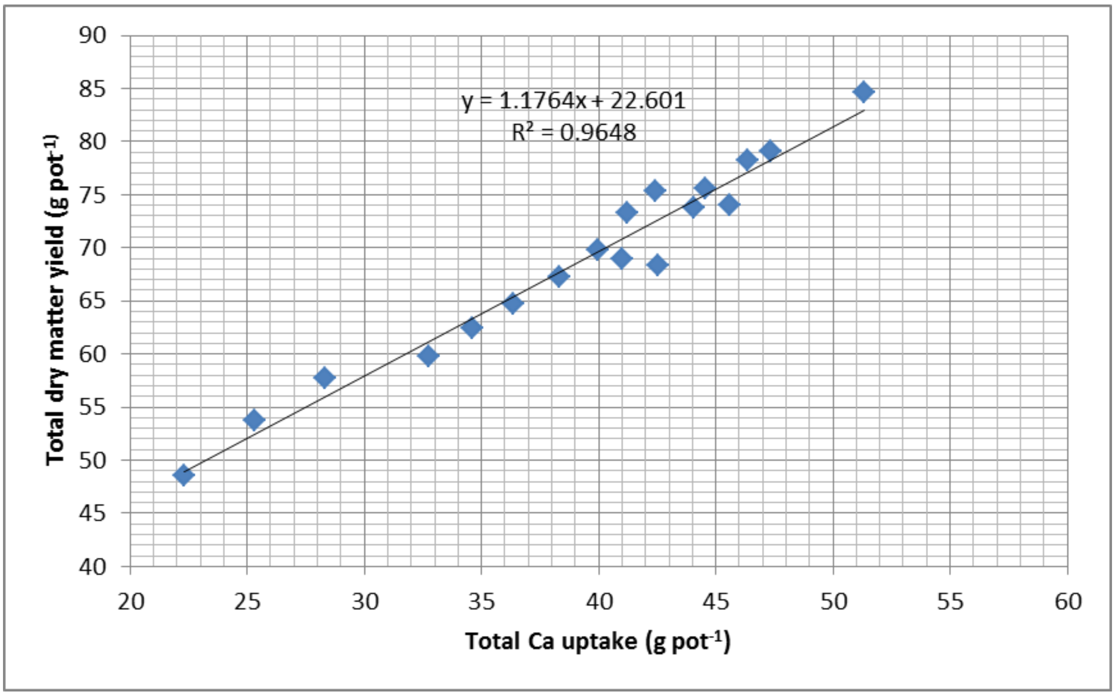


Fig 10: Relationship between total calcium uptake and total dry matter yield of hybrid napier grass

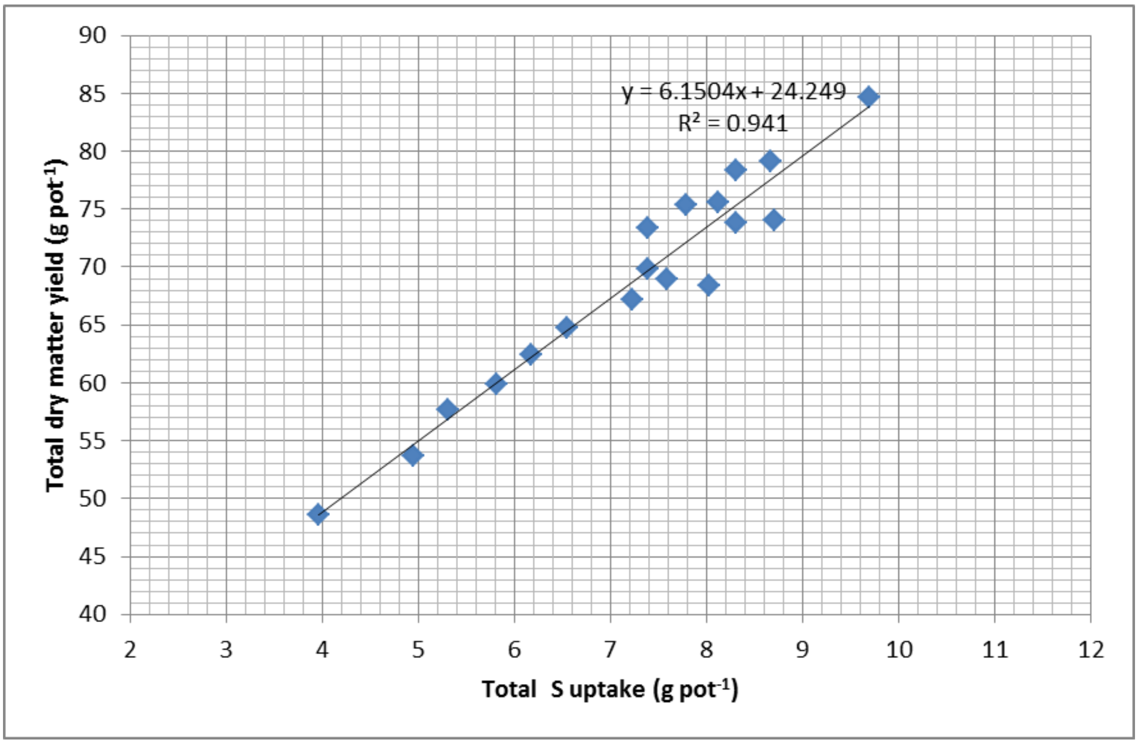


Fig 11: Relationship between total sulphur uptake and total dry matter yield of hybrid Napier grass

Discussion

Properties of soil and organic manure used

Dissolution of phosphate rock is favoured by low pH, Ca and P because such a situation provides protons and Ca and P sinks (Ranjan *et al.*, 1996, Szilas 2002) [36, 43]. The P component of UPR dissolves in moist soil as per the following reaction - $Ca_{10}(PO_4)_6F_2 + 12H^+ \rightleftharpoons 10Ca^{2+} + 6H_2PO_4^- + 2F^-$

The dissolution rate depends on the supply of H^+ ion (Kanabo and Gilkes, 1987a) [26] and lowering of Ca^{2+} and $H_2PO_4^-$ ion activities through diffusion or adsorption reactions (Bolan and Hedley, 1989) [7]. The pH of the three soils used in this study were S_1-4.15, S_2-5.03 and S_3-5.83, which provides a conducive environment to denote H^+ ion for dissolution of URP. Bolan *et al*., (1986) and Tambunan (1988) [8, 44] reported that the pH of top 10cm soils with pH 5 to 6 were sufficient to dissolve 2.3 to 7.8 t North Carolina PR per hectare under adequate moisture condition.

Lower available P (8.92-15.74 kg/ha) and exchangeable calcium (1.32-1.50 c mol (P^+) kg^{-1}) content of these soil provide a sink for dissolution of RP. Diffusion and adsorption of P on soil surface or by crop removal decrease the P concentration around PR particles and favour dissolution of PR (Kirk and Nye, 1986b, White 1988b, Kanabo and Gilkes 1987a) [27, 48, 26]. According to mass action law, PR dissolution releases Ca ion and soil with high Ca content would slow down PR dissolution (Hammand *et.al.*, 1986b). For many

tropical acid soils, exchangeable Ca is relatively low, thus providing favourable condition for PR application.
The nutrient composition of FYM (N, P, K, and Ca) makes it a fairly good amendment on acidic laterite soils.

Effects of treatments on available P

The findings of the present study indicated that soil pH in all treatments increased significantly from its initial value upto fourth cutting and then decreased till 8th cutting but remained above the initial value. The increased in soil pH can be attributed to the release of Ca due to dissolution RP. Increase in pH and Ca has a positive impact on reduction of P sorption capacity and exchangeable Al in acid soils. Combined application of SSP or lime with URP maintained higher pH during initial stage of growing period resulted in instant release of Ca from these sources over the period.
The data of the present investigation revealed that there was increase in available P in all treatments except control upto 5th cutting and there after declined with decrease in soil pH. The decline in soil available P with progress of time can partly be attributed to crop uptake which is continuous throughout all cuttings. Phosphorus adsorption, precipitation and lack of P source could have been led to declining available P in control. Mokwunge *et al*. (1996) [32] reported that P deficiency in acid soils is often associated with high P-fixation between pH 5.0-6.0 where H_2PO_4 dominates (Furihata *et al*.,1992) [16]. Halford observed that more than 80 % of applied P in acid soils undergoes adsorption, precipitation or conversion to the organic form. The higher level of available P in URP+SSP treatment could be possible due to addition of water soluble P (SSP) as well as reduction in P- fixation with increase in soil pH. Combined application of lime with SSP increased soil pH and exchangeable Ca that reduces the P-fixation and increased available P. Dissolution of URP is not affected in both URP+SSP and URP+lime treatment since crop uptake acts as a strong sink for Ca and P. The lower level of available P in URP alone (T_2) during initial stage was associated with slow dissolution of URP but, in long run the values were comparable with URP+SSP or URP+lime. Combined application of URP with FYM or PSB also increases available P through chelation and decomposition. The decomposition products of organic materials lowers the activity of Fe and Al which form insoluble salts with P so liberate phosphorus (Geolhoed *et al*. 1999) [17]. Inclusion of PSB with URP also recorded similar effect on soil pH and available P. PSB application enhances dissolution URP through production of organic acid and chelating substances. (Adhya *et al*. 2015) [1].

Biomass yield and phosphorus use efficiency of hybrid Napier grass

The lower biomass yield of hybrid Napier grass in control (48.6 g pot^{-1}) may be attributed to the low available P due to fixation in acid soil. Conversely, the supply of P and Ca by P sources (URP, SSP) and amendments (lime, FYM, PSB) in combination contributed significantly higher biomass yield. Mishra and Pattnaik (1997) [30] reported similar results of hybrid Napier grass in acidic sandy loam soil (pH 5.6) in Odisha. The dry matter yield, P uptake and RAE of grass in Jordan PR or North Carolina PR were higher than SSP treatment. Onwonga *et al*. (2013) [33] reported that application of Minjingu PR alone or in combination with FYM or lime in acid soil (pH 4.7) of Kenya increased available P, P uptake, PUE and maize yield over control.
Subehia and Minas (1993) [41] observed that addition of URP with FYM or poultry manure increase the wheat yield and P uptake in clay loam soil with pH 5.7. The organic manure enhanced the dissolution of PR or chelation of Ca^{2+} ions and subsequent lowering of Ca^{2+} ion activity in a soil solution providing a sink for Ca^{2+} (Wright *et al*. 1992) [50].
Under certain field conditions such as high pH, short duration crop or low reactive PR, the agronomic efficiency of PR may not be feasible as that of SSP. Combined application of PR with SSP can be effective under certain condition. In present study URP and SSP mixture in 1:1 ratio recorded higher biomass yield (47 %) in S_3 (soil pH 5.82) than URP+lime (37 %) or lone URP (36 %) treatment.But it was inferior to these two treatments in S_1 (soil pH 4.15) and S_2 (soil pH 5.08). Similar observation was made by Prochnow *et al*. (2004) in Brazil for wheat and rye grass with PR : SSP combination at 1:1 ratio because the water soluble SSP provides P to crops initially (starter effect) resulting better plant root development, which in turn allowed the plants to utilise PR more effectively in latter stage of growth. Such a mixture further reduces the P-fixation by depressing the activity of free Fe and Al in soil solution and enhance the solubility of PR by action of initial acidity created in root rhizosphere (Mc Lean and Wheeler 1964) [29].
Higher dose of URP (T_2-200%P) recorded higher biomass yield of napier grass in S_1 and S_2 (41-44 %) than URP+SSP (38 – 41 %) or URP+lime (37-42 %) treatment because of higher dissolution of URP due to low pH, low available P and low exchangeable calcium content in soil during entire crop period.
Inclusion of lime with URP (T_6) was found to be inferior to URP alone (T_2) in S_1 and S_2 since liming increases soil pH limiting the dissolution rate of URP and P availability although decreases the activity of Fe and Al. Therefore it is necessary to fix lime rates carefully to alleviate Al-toxicity problems, at the same time to avoid adverse effect on PR dissolution (Hammond *et al*. 1986b; Chien and Friesen, 1992) [19, 11].

Relative agronomic efficiency (RAE) of Udaipur rock phosphate (URP)

The RAE values of treatments indicated that URP is as effective as combined application of URP with SSP or amendments depends on soil pH. In low pH soil URP alone recorded higher RAE (76-108%) than other combinations which promotes the dissolution of URP. Similar findings had been reported by Akande *et al*. (2005), Akintokun (2003) [2, 4].
The agronomic effectiveness (capacity of P supply to crops) of PR depends on the soil condition (Zapata and Ray, 2004, Hammond and Lean, 1983). Thuita *et al*. (2005) [51, 20, 45] reported that the acidic soils of Siaya, Western Kenya with pH 4.76 was ideal for favourable solubilisation of PRs. Akinrinde and Okeleye (1995) [5] reported that crop species to be grown as well as soil pH should be considered for efficient utilisation of sparingly soluble phosphates for both short and long term effects in crop production.

Phosphorus, Calcium and Sulphur uptake by hybrid Napier grass

Total P, Ca and S uptake by hybrid napier grass in URP+SSP treatment was maximum among all treatments might be due to application of water soluble SSP containing P, Ca and S. On the other hand the uptake in URP+lime treatment was higher than URP alone since lime application increases soil pH and reduces P-fixation in acid soils.

Conclusion

Phosphate rock is a viable alternative to the high cost water soluble P fertilizers in increasing crop productivity in acid soil regions. Use of udaipur rock phosphate alone or with amendments increased soil pH, available P, Ca, biomass yield and P, Ca and S uptake by hybrid napier grass. Higher dose of URP (200% P) alone was as effective as URP: SSP mixture in 1:1 ratio for long duration napier grass as reflected by yield and RAE and can therefore be used as an affordable alternative to the more comprehensive water soluble SSP fertilizers. Effect of FYM or PSB on URP dissolution rate as reflected by soil pH, available P exchangeable Ca and biomass yield of hybrid napier grass was lower as compared to combined application of URP + SSP or URP + lime.

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